 Sub.

DIRECTOR OF CENTRAL INTELLIGENCE
Security Committee

SECOM-D-301
19 December 1977

MEMORANDUM FOR: Executive Secretary, NFIB

25X1A

FROM: [redacted]
Acting Chairman

SUBJECT: National Technical Threat Estimating Guide--Power Supplies (C) Estimating Guide RD/12-76 (U)

1. (S) This memorandum forwards the subject report on power supplies for the information of the Board. The report provides the detailed technical backup to the previously distributed report, National Technical Threat Estimates 1976-1981.

2. (S) This guide is intended to provide the basic theoretical and factual foundation necessary to make sound technical estimates of the technical surveillance threat both for normal and unusual conditions. The guide is expected to be used primarily by technical and engineering personnel in the conduct of detailed technical studies. It will also facilitate preparation of updated estimates as they become required.

3. (U) For additional copies, NFIB members should contact their representative on the DCI Security Committee's Research and Development Subcommittee or [redacted]

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[redacted]

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Attachment:
Threat Estimate
(28 copies)

Classified by 63417

SECRET

SUBJECT: National Technical Threat Estimating Guide--Power Supplies (C) Estimating Guide RD/12-76 (U)

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DIRECTOR OF CENTRAL INTELLIGENCE
Security Committee
RESEARCH AND DEVELOPMENT SUBCOMMITTEE

12 DEC 1977

MEMORANDUM FOR: Chairman, Security Committee

SUBJECT : National Technical Threat Estimating Guide, Power Supplies (C)
Estimating Guide RD/12-76 (U)

1. (S) Attached for your use and retention is the report, National Technical Threat Estimating Guide, Power Supplies. This report provides the detailed technical backup to the previously distributed report, National Technical Threat Estimates 1976-1981. This technical threat estimating guide is intended to provide the basic theoretical and factual foundation necessary to make sound technical estimates of the technical surveillance threat both for normal and unusual conditions. The estimating guide is expected to be used primarily by technical and engineering personnel in the conduct of detailed technical studies. This guide will also facilitate preparation of updated technical threat estimates as they become required.

2. (S) Other on-going studies will relate this technical threat to specific intelligence service capabilities insofar as they are known. Additional copies of this report are available upon request through each member agency's representative on the Research and Development Subcommittee or from the Executive Secretary, Research and Development Subcommittee.

3. (S) You may wish to forward this report to the NFIB for noting.

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Philip K. Eckman
Chairman
Research and Development
Subcommittee

Attachment:
As stated

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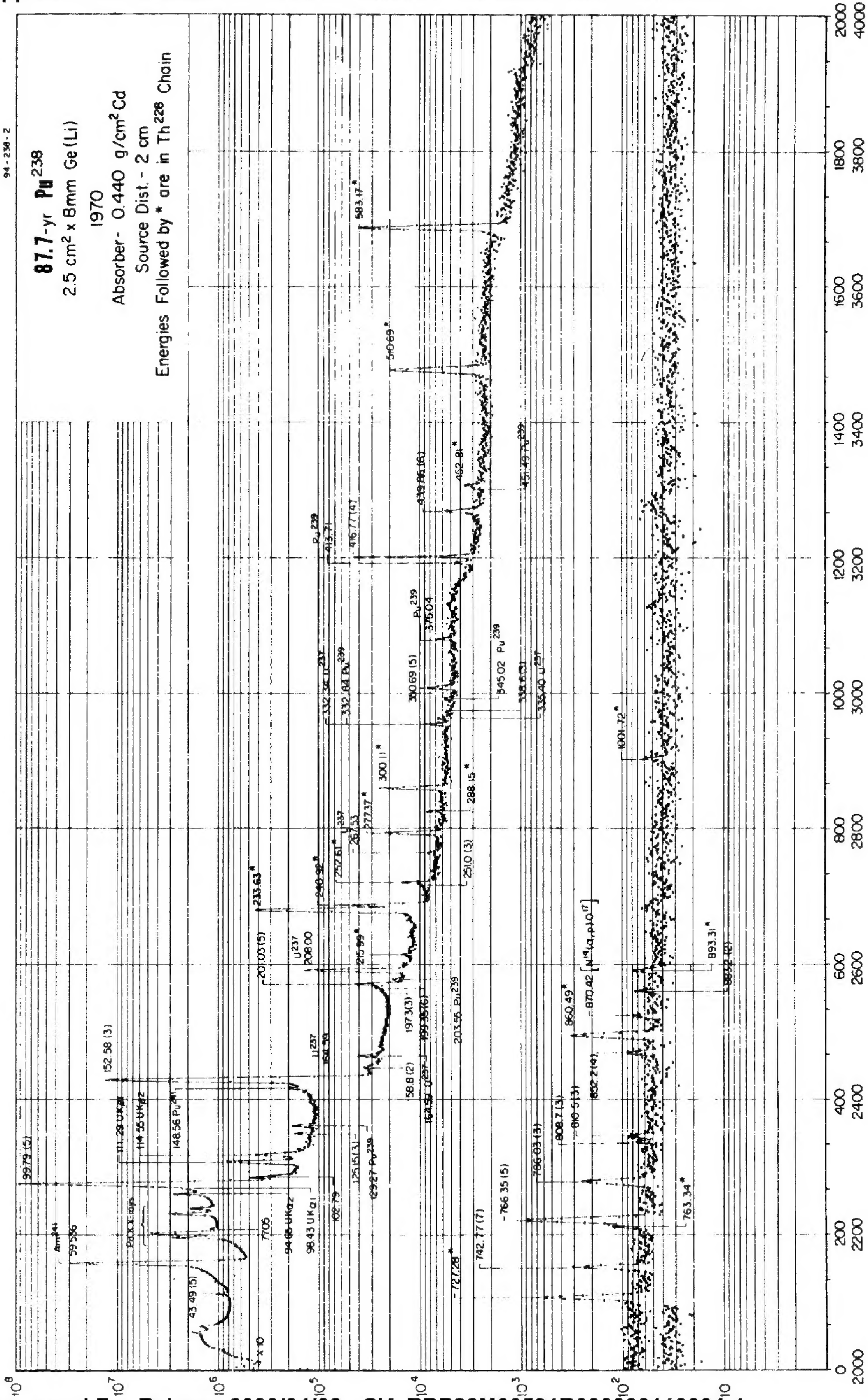
94-238-2
87.7-yr Pu^{238}
2.5 cm^2 x 8mm Ge(Li)
1970
Absorber- 0.440 g/cm^2 Cd
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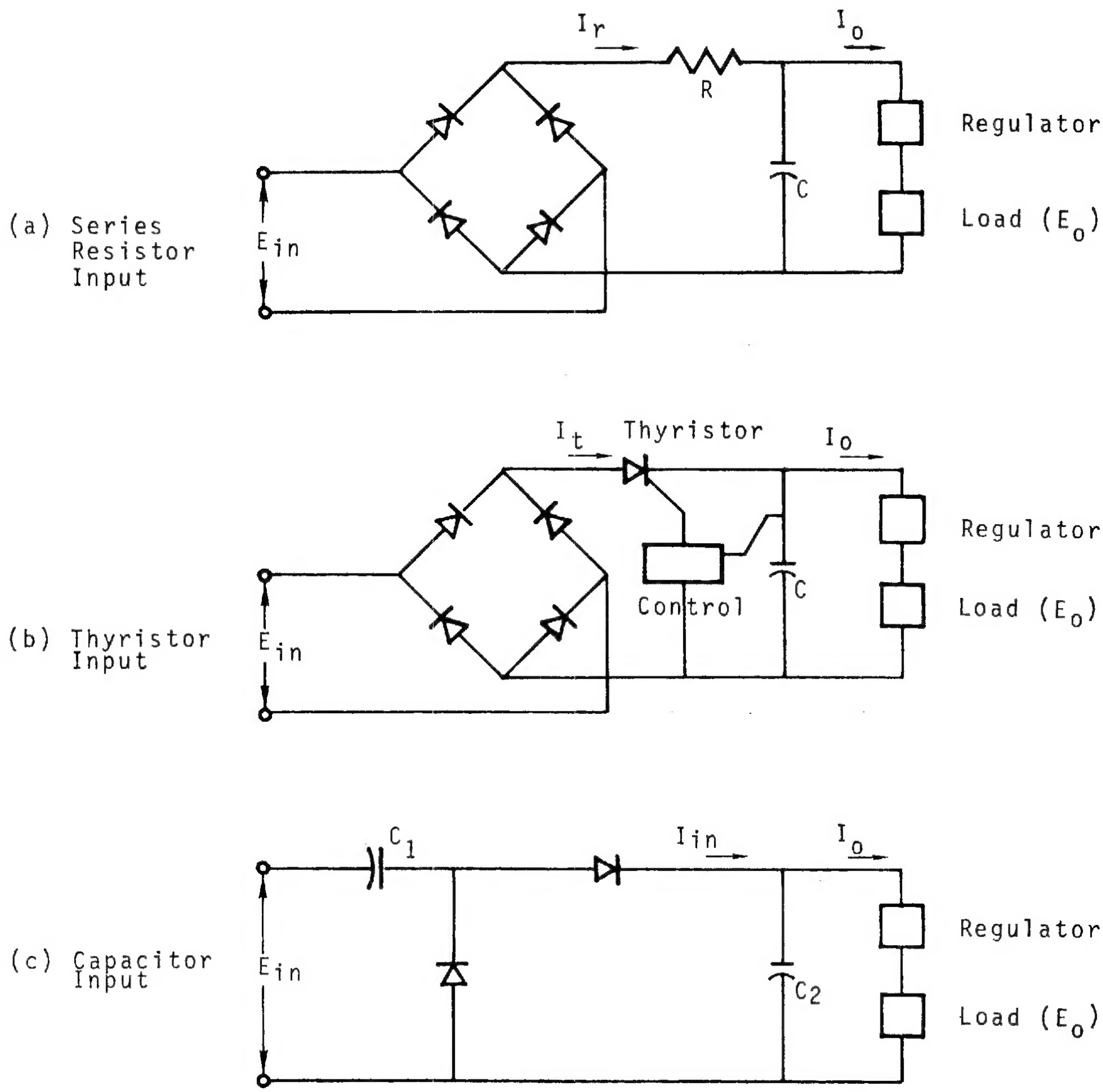

Figure 8. Typical power supplies

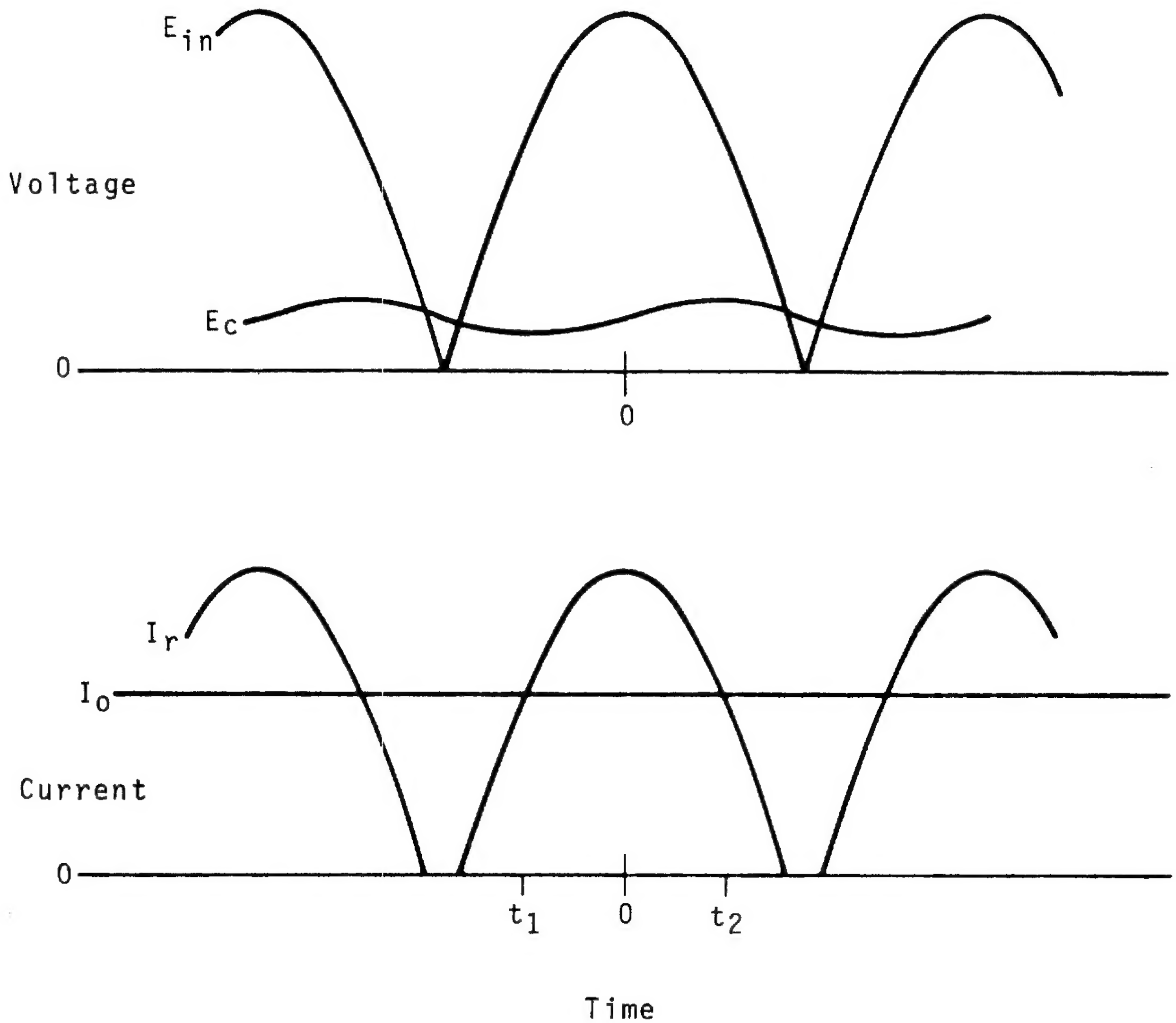

Figure 9. Waveforms for resistor input power supply (E_c ripple is exaggerated)

The load current I_0 is equal to the average current through the resistor:

$$I_0 \approx \frac{E}{R} \cdot \frac{1}{\pi} \int_{x=-a}^{a} \cos x \, dx - \frac{\overline{E}_c}{r}$$

$$= \frac{\frac{2E}{\pi} \sin a - \overline{E}_c}{R}. \tag{8}$$

$$R \approx \frac{1}{I_0} \left(\frac{2E}{\pi} \sin a - \overline{E}_c \right)$$

At the moment t_1 (see Fig. 9), the rising input voltage produces a level of current through R just sufficient to supply the load current I_0. Current to the capacitor is then zero, and the capacitor voltage is at its minimum value, $\overline{E}_c - \Delta E$. Excess input current then flows into the capacitor, bringing its voltage up to a maximum value $\overline{E}_c + \Delta E$ at a moment t_2 during the descending part of the input voltage cycle. We can find an expression defining t_1 by setting the load current equal to the input current:

$$I_0 = I_r \approx \frac{E \cos \omega t_1 - \overline{E}_c}{R}$$

Substituting for R from Eq. 8 gives

$$\cos \omega t_1 \approx \frac{2}{\pi} \sin a \tag{9}$$

the assumed symmetry of I_r means that $t_2 = -t_1$:

$$\cos \omega t_2 \approx \frac{2}{\pi} \sin a \tag{10}$$

From time t_1 to time t_2, the capacitor voltage rises by an amount $2\Delta E$ as current flows into it. The increase in charge is equal to the time integral of that current:

$$2C\Delta E = \int_{t_1}^{t_2} (I_r - I_0) dt$$

$$= \int_{t_1}^{t_2} \left(\frac{E}{R} \cos \omega t - \frac{E_c}{R} - I_0 \right) dt. \tag{11}$$

We have not derived an analytical expression for E_c as a function of time, but its contribution to the value of this integral is relatively small, with E_c typically much smaller in value then E. We notice that E_c will rise as an s-shaped time function between t_1 and t_2—almost symmetrical about the midpoint in time. Since I_r is assumed symmetrical, E_c will be also. Then

$$\int_{-b}^{b} E_c \, dt = 2b\overline{E}_c.$$

Using this in Eq. 11 leads to

$$C\Delta E = \frac{E}{\omega R} \sin \omega t_2 - \left(\frac{\overline{E}_c}{R} + I_o\right) t_2. \qquad (12)$$

We can evaluate the two factors containing t_2 by referring to Eq. 10. After some manipulation by standard trigonometric formulas we find

$$\sin \omega t_2 = \left[1 - \left(\frac{2}{\pi}\right)^2 \sin^2 a\right]^{1/2},$$

and

$$t_2 = \frac{1}{\omega} \text{cps}^{-1} \left(\frac{2}{\pi} \sin a\right).$$

Substituting these into Eq. 12 and substituting R from Eq. 8 leads to an expression for the value of the capacitor:

$$C = \frac{I_o}{\omega\Delta E} \frac{\sqrt{\left(\frac{\pi}{2}\right)^2 - \sin^2 a} - (\sin a) \cos^{-1} \left(\frac{2}{\pi} \sin a\right)}{\sin a - \frac{\pi}{2} \frac{\overline{E}_c}{E}}$$

If $\overline{E}_c$ is small compared to E, then since

$$\cos a = \frac{\overline{E}_c}{E},$$

we can use the approximation

$$\sin a \approx 1$$

so that

$$C \approx \frac{\pi I_o}{2\omega\Delta E} \cdot \frac{\sqrt{1 - \left(\frac{2}{\pi}\right)^2} - \frac{2}{\pi}\cos^{-1}\frac{2}{\pi}}{1 - \frac{\pi}{2}\frac{\overline{E}_c}{E}}$$

$$\approx 0.33 \frac{I_o}{\omega\Delta E}$$

$$= 0.053 \frac{I_o}{f\Delta E}, \tag{13}$$

where f is the powerline frequency (Hz)

An approximate expression for the power supply efficiency can be derived by assuming that the variation in capacitor voltage will be very small compared with the input voltage. Then the input power will be (denoting average quantities by an upper bar):

$$P_{in} \approx \frac{1}{R}\overline{(E\cos\omega t - \overline{E}_c)\, E\cos\omega t}$$

$$= \frac{1}{R}\left(E^2\,\overline{\cos^2\omega t} - E\,\overline{E}_c\,\overline{\cos\omega t}\right) \tag{14}$$

$$= \frac{1}{R}\left(\frac{E^2}{2} - \frac{2E\,\overline{E}_c}{\pi}\right)$$

From Eq. 8,

$$R \approx \frac{2E}{\pi I_o}.$$

Then,

$$P_{in} \quad \frac{\pi I_o E}{4}\left(1 - \frac{4}{\pi}\frac{\overline{E}_c}{E}\right) \tag{15}$$

The overall efficiency of the resistor input circuit is

$$\eta = \frac{E_o I_o}{\frac{\pi I_o E}{4}\left(1 - \frac{4}{\pi}\frac{\overline{E}_c}{E}\right)}$$

$$= \frac{E_o}{\frac{\pi E}{4} - \overline{E}_c} \approx \frac{4E_o}{\pi E}. \qquad (16)$$

An implicit assumption made in this analysis (and in the others to follow)—that the average capacitor voltage is equal to the median between the maximum and minimum values—is based on the symmetry of the waveform. More detailed analysis supports the validity of this assumption.

(b) Thyristor Input

Analysis of the thyristor input circuit is simpler. Figure 10 shows voltage and current waveforms for this circuit. At the time t_1 during each half-cycle, as the rising input voltage matches the capacitor voltage, the thyristor admits current to recharge the capacitor. A charge O is admitted, equal to the charge supplied to the load during the half-cycle. The capacitor voltage rises by an amount $2\Delta E$, just equal to the input voltage rise during the charging time interval:

$$Q = 2C\Delta E = \frac{\pi I_o}{\omega}$$

or

$$C = \frac{\pi I_o}{2\omega\Delta E} = \frac{I_o}{4f\Delta E}. \qquad (17)$$

The circuit efficiency is

$$\eta_t = \frac{E_o \; I_o}{E_o \; I_o + \overline{E}_{reg} \; I_o} = \frac{E_o}{\overline{E}_c}. \qquad (18)$$

The capacitor voltage rises almost linearly during the brief charging period and falls precisely linearly during the discharge period. Thus, the average capacitor voltage is at the midpoint of the overall swing, and the extreme values are given by $\overline{E}_c \pm \Delta E$.

(c) Capacitor Input

Figure 11 shows the capacitor-input circuit waveforms. An approximate evaluation of the capacitor values is easily obtained if we assume that the ripple voltage on capacitor C_2 is small compared with the peak input voltage E. At the beginning of each flow cycle of the input current I_{in}, the current remains zero until the input voltage rises from its minimum value by an amount equal to the voltage on capacitor C_2, which we can take as the average value $\overline{E}_c$. After this time (t_1), the input current is given approximately by

$$I_{in} \approx C_1 \frac{d}{dt} E_{in} = -I_m \sin \omega t \qquad (19)$$

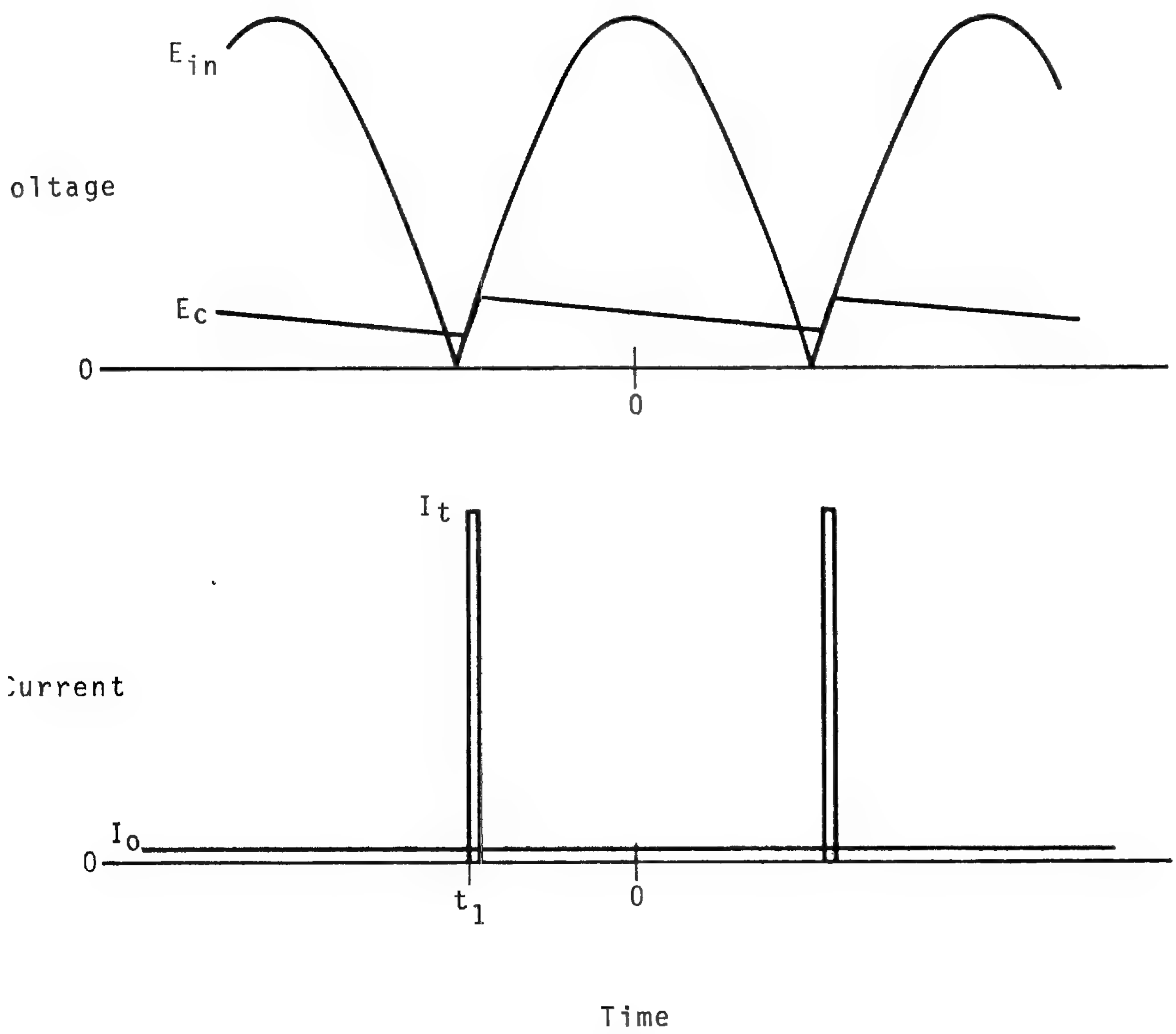

Figure 10. Waveforms for thyristor input power supply (E_c ripple exaggerated)

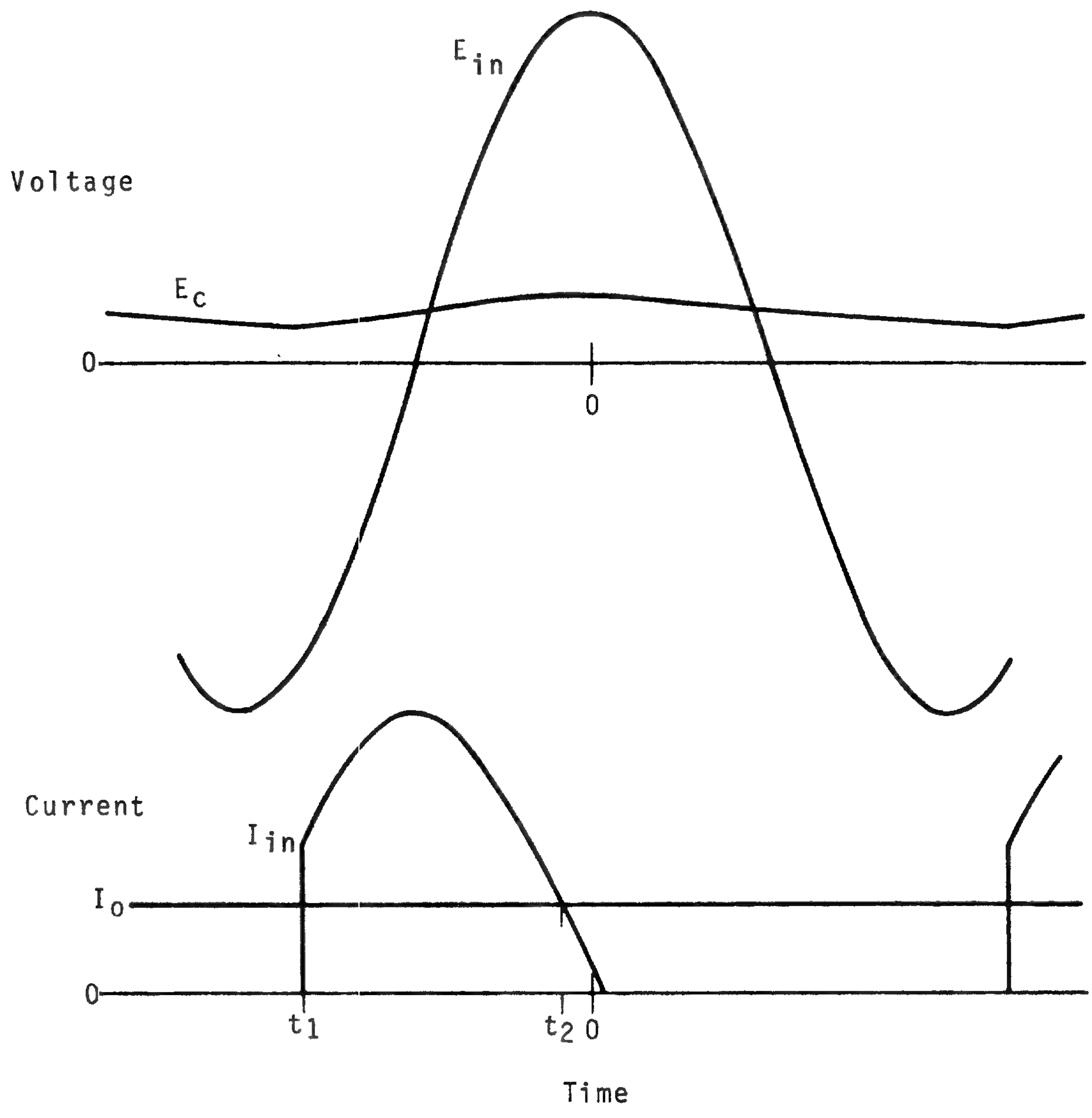

Figure 11. Waveforms for capacitor input power supply (E_c ripple exaggeratd)

if

$$E_{in} = E \cos \omega t$$

and

$$I_m = EC_1\omega. \tag{20}$$

The value of I_{in} at time t_1 may by less than or greater than the average current I_0, depending on the value of E_c relative to E. We will assume that it is greater; the distinction has only a second-order effect on the results to be obtained. The value of time t_1 is

$$t_1 = -\frac{1}{\omega} \cos^{-1}\left(\frac{E_c}{E} - 1\right)$$

The average value of the input current must be equal to the steady load current, so

$$\begin{aligned} I_0 = \overline{I}_{in} &\approx \frac{-\omega}{2\pi} \int_{t=t_1}^{0} I_m \sin \omega t \, dt \\ &= \frac{I_m}{2\pi}\left(2 - \frac{E_c}{E}\right). \end{aligned} \tag{21}$$

At a later time t_2 the input current falls again to equal I_0:

$$I_0 = -I_m \sin \omega t_2,$$

so that

$$t_2 = \frac{1}{\omega} \sin^{-1}\left(\frac{-I_0}{I_m}\right)$$

from Eq. 21.

During the time interval between t_1, and t_2, I_{in} is more than sufficient to supply the load current I_0, and the excess goes into charging capacitor C_2,

raising its voltage from $E_c - \Delta E$ at time t_1 to $\overline{E}_c + \Delta E$ at time t_2. The net charge increase is

$$Q_2 = 2\ C_2 \Delta E = \int_{t_1}^{t_2} (I_{in} - I_o)\ dt$$

$$= -I_o \int_{t_1}^{t_2} \left(\frac{I_m}{I_o} \sin \omega t + 1 \right) dt$$

$$= \frac{I_o}{\omega} \left[\sqrt{\left(\frac{I_m}{I_o} \right)^2 - 1} + \frac{I_m}{I_o} \left(1 - \frac{\overline{E}_c}{E} \right) - \omega (t_2 - t_1) \right].$$

Evaluation of this expression with the condition

$$0.01 \leqslant \frac{\overline{E}_c}{E} \leqslant 0.1$$

shows that

$$3.4\ \frac{I_o}{\omega} \leqslant Q_2 \leqslant 3.8\ \frac{I_o}{\omega}.$$

Using the median value for Q_2 gives

$$C_2 \approx 1.8\ \frac{I_o}{\omega \Delta E}$$
$$\approx 0.29\ \frac{I_o}{f \Delta E}. \tag{22}$$

We can evaluate C_1 from Eqs. 20 and 21:

$$C_1 \approx \frac{\pi I_o}{\omega E} = \frac{I_o}{2 f E}. \tag{23}$$

As for the thyristor input circuit, the only power loss is to the regulator, so that

$$\eta_c = \frac{E_o}{\overline{E}_c}. \tag{24}$$

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